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Real Time Optical Interferometric Image Addition and Subtraction by Wave Polarization

by

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Prepared for

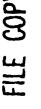
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## DEAL-TIME OPTICAL INTERFEROMETRIC IMAGE ADDITION AND SUBTRACTION BY WAVE POLARIZATION

#### **ABSTRACT**

A real-time coherent optical interferometric image addition and subtraction system based on a technique similar to an earlier work by Kunstmann and Spitschans is extensively investigated.

Theoretical analysis of the system has been compared with experimental data obtained. Distortion and resolution power of the system with respect to the size and positions of the input images have been analyzed in detail.

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## REAL-TIME OPTICAL INTERFEROMETRIC L'MAGE ADDITION AND SUPERACTION BY WAVE POLARIZATION

#### 1. Introduction

Optical frace addition and subtraction by holography and inter-Teromotry 'T have been investigated by various researchers. In fact of the interferemetric methods, complex amplitudes of two images from different ent light paths of an interferometer are recombined by a grating or 1. an ordinary holographic beam splitter. By introducing a phase difference of m into one of the paths, the subtraction between the two images can be achieved. However, in the method used by Kunstmann and Snitschan, an analyzer was used to produce opposite phases for the two spatially secarated in Fig. and a Wollaston prism was used for the recombination of the two images. The method is commaratively simpler and offers the following advantages. It is easier to change the phase difference between the imaging paths of the two indues since this can be achieved by simply rotating the analyzer. The fracting paths of the two images are relatively closer to each other than those in the cyster using a Mach-Zehnder interferometer." Hence the method is less vulnerable to environmental vibrations. Furthermore, no holographic bearsplitters or gratings are required. The birefringent Wollaston prise is commercially available. However, although Kunstmann and Spitschan<sup>5</sup> reported that subtraction has been performed in an area of 3mm by 3 mm in their experiment, no theoretical analysis of their experimental results with regard to the various optical components such as the lens and Wollaston prism have been given. For example, they have not taken the aberrations of the Wollaston prism and the precision of the coincidence of the two images into

consideration. The spherical abertation of the Wollaston prism in their system can introduce errors in the addition and addition and the last efficiency in the cystem is low. For this reason, we have investigated an improved system. The details of the theory, experimental results, and experimental data analysis of the improved system are described in the following Sections.

#### II. Theoretical Discussion

The basic principle of the technique of performing real-time image subtraction and addition using polarization modulation can be illustrated with the assistance of Fig. 1. Besides ordinary polarizers, a special polarization element used is called a Wollaston prism.

In Fig. 1. S is a coherent point light source, C is a collister,  $x_1$  and  $x_2$  are two transparencies with their amplitude transmittances  $x_1(x_1,x_2)$  and  $x_2(x_1,x_1)$  representing respectively the two input signals being the costed. The center of  $x_1$  is located at  $(-x_0,0)$  and that of  $x_2$  is at  $x_1$ . In the input plane  $x_1$ , and both of them are inclined at an arc angle—to the 2-axis as seems in Fig. 1. The input plane  $x_1$  is located at the tent focal plane of the lors  $x_1$  and the output plane of the system is at the cack focal plane of leas  $x_2$ . P is a polarizer and AN is an analyzer. In and  $x_2$  are two modulation polarizers located in front of the input transcentions  $x_1$  and  $x_2$  respectively. The unit-vectors along the directions of the principal transmittance of P, P<sub>1</sub>, P<sub>2</sub>, and AN, represented by P, P<sub>1</sub>, P<sub>2</sub>, and A respectively, are shown in Fig. 2. W is a Wollaston prism which is located at the vicinity of the back focal plane of  $x_1$  and  $x_2$  respectively.

For simplicity, we shall assume that the two lenses  $\rm L_1$  and  $\rm L_2$  have the same focal length f and have perfect image formation properties with

the input plane  $I_1$  and output plane  $I_2$  as a pair of conjugate planes. Since the spherical waves radiated by the points at the plane  $I_1$  are transformed into plane waves by lens  $E_1$ , the Wollaston prism though can introduce distortions but will not induce any other monochromatic aberrations for objects at plane  $I_1$ .

The complex, vectorial amplitude distribution of the illuminating light at  $I_1$  may be represented by P. As a result of the polarization modulation of  $S_1$  and  $S_2$ , the amplitude distribution  $I_1$  immediately begin the input plane is

$$I_{1} = \{ (x_{1} + x_{0}, y_{1}) | P_{1} + S_{2}(x_{1} - x_{0}, y_{1}) | P_{2} \}$$
(1)

In there is no Wellaston prism in the system, the different poll of ration lates of  $\S_1$  and  $\S_2$  would not affect their image locations, and the two images would still be separated at the output plane  $\S_2$ . However, when the prior is in place, the situation is different. The Wellaston , ris will deflect the light beams passing through it according to the polarization state. As can be seen in Appendix A, the values of the angle, of deflection for beams polarized along  $\S_1$  and  $\S_2$  are both approximately equal to:

$$\tau = \tan A \cdot n_o - n_e$$
 (2)

where A is the apex angle of the Wollaston prism defined in the Appendix,  $n_{\rm o}$  and  $n_{\rm e}$  are the refractive indexes of the prism corresponding to the ordinary and extraordinary beams respectively. However, the directions of the deflections of these two beams are opposite to each other. Thus, if we adjust the distance  $x_{\rm o}$  to make the angle of inclination obe equal to the angle  $\epsilon$ , the centers of the images of  $S_1$  and  $S_2$  can both be shifted to be on the z-axis in the output plane and hence the two images will

coincide. Inmited by distortions, with each other (see Appendix A). Neart from an emproximately aniform applitude attenuation and constant place retardation (see IVA). Tell, spart from a complex constant, the but it applitude. The first of the continued in a political an analyzer A being placed. In third of IVA has income period as as:

$$i = \frac{\sqrt{2}}{2} \left[ 5_1(x_2, y_2) i_1 + S_2(x_2, y_2) F_2 \right]$$
.

When AW is placed in front of  $I_2$  as shown in Fig. 1; due to the relationship among P, P $_1$ , P $_2$  and A (Fig. 2), the output becomes

$$0 = \frac{1}{2} \left[ S_1(x_2, y_2) - S_2(x_2, y_2) \right] A .$$
 (3)

The image subtraction between  $S_1$  and  $S_2$  can thus be achieved.

Moreover, the flexibility of the proposed system can be seen by the fact that becader in the processing capabilities can be attained by some legislation of the relative angular positions of P and A. Tient, we make the the departize sion in Eq. (3) is caused by a "crossed NF-12 gas etyp, i.e., I = I as snown in Fig. a. if we notate A by 30, a man-alls: NESSE are stray a comined on I the output then becomes

$$\delta = \frac{1}{2} \left[ (\gamma_1(x_1, y_2) + S_2(x_2, y_2)) \right] \hat{A}$$
 (4)

and hence image addition can be achieved. Secondly, if a linear coefficiation of the two images is desired, we can simply rotate AN (or P) to obtain the following output,

$$\vec{0} = \frac{\sqrt{2}}{2} [S_1(x_2, y_2) \cos \beta + S_2(x_2, y_2) \sin \beta] \hat{A}$$
 (5)

where r is the angle between A and  $P_1$  and the "-" and "+" signs correspond

to the depondtries shown in Fig. D(a) and Fig. 3(b) respectively.

The simple and convenient technique for the linear combination of these image, has its practical importance. For example, in image subtraction, the two transparencies usually do not have the same transmit tance over the supposed-to-be identical portion of the two images does to the differences in emulsions or the exposure and development conditions. Thus, in order to carry out a true subtraction, a "weighted" subtraction or a linear combination is required for the removal of the pseudo-differences.

#### III. Experimental Results

A. The experiments, set-up

time ageninental system is natically constructed according to the diamon flows in Figure 1 with blight modifications. A 50 rW He-Ne 1 com was used as the light source, the polarizer P is placed in the raw laser beau before the collinating lens C. The polarized beam, after beam, expanded through a pin-hole spatial filter, was collimated by a 6-irch specturn so-inch foral-length telescopic lens C. It was found that the polarizers  $\Gamma_2$  and  $\Gamma_2$  were not required. In that case, each input image produces two spatially separated images at the output plane, and the useless one can be easily blocked. The rest of the system remained the same except that the imaging lens L<sub>2</sub> was inserted between the analyzer AN and the final outbut image  $L_2$ . Five different lenses have been used at the position of  $L_1$ for the purpose of finding out the influence of the Fourier transform on the effect of subtraction. The important characteristics of the lesses are listed in Table 1. The Wollaston prism is made of calcite, with its front surface area of 10mm by 10mm, total thickness of 6 mm, and the split angle of  $5^{\circ}$  (the abox angle A = .245 rad.).

During the experimental propers, the looses listed in Table I were me by one repliced at I, of Fig. 1 and the output image at 1, of the large figure was diserved classic. When there was 10 specified images being placed it In place, the adstraction was performed between two open source. It by and by at 1 in 1. It has been found that the two mossible alc: axis extentions. The intening to Country transform lens has a significacant introduced the result of subtraction. The subtraction between the two open spaces yields in inference tringes which will be analyzed in the next Section. Then the Fourier that form lens is placed with one of its two surfaces facing toward the light source (say Orientation 1) broader Interference fringes can be obtained than when the surface is placed facing away from the light source (say Orientation 2). The phenomenon, common to all the lenses listed in Table I, is further illustrated in Figs. 4-9. Figures 4 and 5 present the photographic recordings of the interference frinces where the fourier transform lens  $\mathsf{L}_\mathsf{T}$  was placed along Orientation 1 and 2 insight only. The various parts in these Figures indicate the different is did to at the Wollaston prism along the optical axis. When the Wollaston prism was placed at position a, the dark fringe has a miximum area in the interference tringe nattorn. It can be seen that this is true for obtained Fig. 1 Grawher, the act acts of Figures 6-9 are photographic recordings of

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the pater's rence formers where the the theory of the part to be and the Wol aston prior was so positioned that the dark fringer is a winded. The boarts of the same Figures correst and to the elementation there have been elaced alone Crientation. In the system but with the Wollaston prism arbitrarily positioned. It has been found that along Orientation 2, no matter how one adjust the profition of the Wollaston prism, there was no way to obtain a preater dark fringe area than those obtained with the lens alone Crientation 1.

It is important to note that the dark fringes caused by the destructive interference of the areas in the two open spaces at the input increplane are the usable areas for the performance of the subtraction. Therefore, we have attempted to maximize the dark fringes in the interference fringe patterns created by L<sub>I</sub> through by each along the two possible axial orientations. The results of computations of the maximum x- and y-dimensions of the dark areas from some of the photographs of Figures 4 through 6 to 6. Lest accuracy as one can estimate are listed in Table II. Although the cases turn area door not equal to XY for each of the cases listed in Table II. The needs that Less listed along Orientation I would yield the maximum area for subtraction in conjunision with the other lesses.

 Results of subtraction between two specific input images -a penny and a metal washer.

Since  $L_{\rm II}$  placed along Orientation 1 has yielded the maximum area of the dark fringe, it was chosen for the Fourier transform lens. Two

injut that some being and a metal washer, are placed respectively at 5. and  $\Sigma_{p}$  at the input place  $I_{1}$ , of Fig. 1. I uniform transparent also place was placed at I, to support the pency and washer. The two object are attained to the olist plate by double-stick tanet. The discerence the penny is approximately 19 mm (1/4"). The metal wisher has an out like dimpeter of approximately 9.52 mm (3/8) and a hole in the center of  $\omega$ diameter of about 4.76 or (3/16"). The photographic recordings showing the subtraction results are presented in Fig. 11. The approximate centerto-confor distances between the penny and washer are 70 mm (2.3/4"), 63.5 mm (2 1/2") and 60 mm (2 3/3") for a, b, and c part of the pie graphs in Fig. 11 respectively. These photographs have illistrated to partial overlapping, jet complete overlapping, and polition of the washer and the benny in the citout flace as a result of the subtraction of the original objects that are placed grant. The doce areas of the number of the sastem vividly demonstrated the addition tion premovesor. The thin hair-like pecins between the upper parts of the benny and the waster is an indication of the resolution of the subtraction. The irregular traces of marks in the lower portion of the permy was disted by the dive left by the penny on the glass plate. It can be seem from the timee parts in Figure 11 that the residue glue did not wromen its position when the penny was moved. The glue mark is also an indication of the resolution of the system.

#### IV. Data Analysis

In order to understand the subtraction system thoroughly, the intertorence fringe patterns as shown in Figs. 4-10 require a theoretical intercretation and the decree of accuracy of the subtraction results needs to analyzed. We shall discuss these two aspects of the system as follow.

#### A. Interpretation of the interference fringes

fringe pattern easumes that all optical components used in our system of optically perfect, i.e., the lenses are free of aberrations. The reason that the fringer appear at the outposhing is mainly due to the fact that the fringer appear at the outposhing is mainly due to the fact that two different palarizes that may emission that the outposhing as estable order exist an tre outposh Cane Thoulars. I am temperature that the outposhing as estable order exist an tre outposh Cane Thoulars. I am temperature that the outposhing as estable order exist an interpretable of the Williams of the outposhing as each of a second order of the outposhing of the outposhing of the outposhing of the outposhing of the limit ray concept. The light may concept is broad or the approximation of purposhing optics, since we assure that the energiage of light diffraction may be neglible in the present case. More determined the model are presented below with the help of some illustrations.

A part of the image processing system of fig. 1 is shown in fore fire details in Fig. 12. Point  $p_3$  is a certain point with coordinate:  $(p_3,p_2)$  on the output plane. Based on the principle of geometrical potics, it is not difficult to find the locations of the two input plane points  $p_1$  and  $p_2$  that correspond to the output point  $p_3$ . Since in the idealized case under the assumption that the system is true of aberrations and diffractions,  $n_1$   $(on p_2)$  and  $p_3$  or a pair of confucated object/image noints. The optical path between  $p_1$   $(on p_2)$  and  $p_3$  can be evaluated along any raw passing throughout of them. To be specific, we choose the rays originating from  $p_1$  and  $p_2$  that are parallel to the optical axis before they reach the Fourier transform lens. Hence the two rays would intercept at the back focal pair of the lens.

•

to the metallical Prostration in and the vicinity of the Walle to enum, ing 13, is arawn for the collect' maths of the mays that ha three, a the mollaston seriou. From in. 14, it can be seen that the path length difference between  $P_1 P_2$  and  $P_2 P_3$  is equal to the path lea difference between (BCD-EM) and (EGHJ-EM). Based on this path lengt difference, we have calculated on a digital computer the interference fringe patterns. Other pertinent data used in the calculations include the wavelength  $x \approx 632.8$  nm; the thickness of the Wollaston prism a =6.0 am, the apex angle of the Wollaston prism A = 0.245 radians; the ordinary refractive index  $n_0 = 1.6584^*$ ; the extraordinary refractive index  $n_a = 1.4754^{\frac{1}{4}}$ . The focal lengths of the Fourier lens and the incoming lens are both equal to f = 750 km; the ranges of the position of the positive  $(x_3, x_4, y_4)$  are  $-100 \text{ am} + x_3 + 100 \text{ cm}$ ;  $y_3 = -166.7 + y_4 + -166.7 + z_5$ the localism of ., varies with  $2x_3 = 2$  km and  $2y_3 = 3.3$  regulate first). the distance a between the front surface of the Wollaston brise and the back femal points Morthe Fourier transform lens is taken an altamat which varies read 1.7% mm to 2.00 mm with a step increment of 2.0% m to account for the in-cois adjustment of the Wollaston prish in the 27560.

thown in Fig. 14 where the interference fringes are represented by dots and B's. The dots denote that the absolute value of a fraction of the math length difference introduced by the Wollaston prism at  $p_3$  is less than  $\lambda/4$  or greater than  $3\lambda/4$  and the letter B denotes that the absolute

<sup>\*</sup> These indices are for wavelength  $\lambda$  = 589.3 nm; for  $\lambda$  = 632.8 nm tracellulated patterns would be slightly different.

value of the path length difference is between  $\frac{33}{4}$  and  $\frac{33}{4}$ . Thus, if the analyze  $\ell$  in the line but introduce any additional phase differences the dots stand for the 'bright' trives and the 'B's stand for the interpretations and the 'B's stand for the interpretations and the 'B's stand for the first rest of the interpretations will be between a differences are distinctly as a large factor of the period of the period of the period of the interpretations will be between the proportion of the large of the period of

of the friends is at minimum and the relatively uniform area of the friends. Shat minimum and the relatively uniform area of the incomparison fringe is at its maximum. The maximum dark area is best for performing image subtraction. The theoretically predicted phenomenon has been ably qualitatively verified by the expanimental results. Any quantitative difference between the computed and experimental data probably is caused by the immediately of the Mollaston prism and the aberrations of lenses. The phenomenon that the fringe patterns are different for a certain lens at the fundifferent orientations can also be explained by the fact that the substraction is dependent on the orientation.

. The ammortion, at the outrat plane.

We shaden the fact that the angular deflection of the light may be the Westerden error are six veries with the incident angle at the front surface of the prists, are independent augenposed of the output plane cannot totally conclide with each other. Both images suffer from different amount of distortions. The resolution power of the subtraction technique is lighter by these distortions. In the following, we estimate how serious the distortion is and try to find out the optimum positions of placing the two input images where the distortions can be minimized. For simplicity, the calculation is done only for one-dimensional case. We assume that the Wolfaston prism has the same parameters as those in the A part of this

Section and that both the fearer lens and the immediate lens have the case theal length r = 1 (arbitrary unit), thus the casmification of the whole cystem is 1.

では、一般のでは、大きなない。

The calculation is based on the configuration as shown in Fig. 18. First we proose a point Cy on the sutput image and then trace back along the geometrical obtical paths to two corresponding points  $\mathbb{C}_1$  and  $\mathbb{C}_2$   $\sim$ the two input transparencies. We shall call the points  $C_1$ ,  $C_2$ , and  $C_2$ the centers of the respective images. Likewise, for any point  $\varepsilon_3$  on the output, the corresponding input image points  $p_1$  and  $p_2$  on the input can also be found. We further let  $\mathbb{N}_1=\pm(C_1P_1)$  ,  $H_2=\pm(C_2P_2)$  , and  $H_3$  $\{\hat{v}_{i,j}^{(n)}\}$  where the positive sign is chosen if the vector is parallel t the positive x-pxis. If there is no distortion,  $\Gamma_1$  :  $\Pi_2$  =  $\Pi_3$ . The differences  $k_{\rm p} + k_{\rm p}$  and  $k_{\rm p} + R_{\rm p}$  can be used to seasons the amount of do tonthe and the difference  $\mathbb{R}_{\tau}$  -  $\mathrm{H}_{2}$  can be used to determine the merelution of softraction. For example, according to our calculated results, if the coint at the intersection of the output place and the optical axis a in sensing  $C_2$ , in h  $C_1$  and  $C_2$  will have their X-coordinate volumes of SD. Sec and 0.0474 respectively, where all units are considered to be the same as that of the right length. An output image point  $\theta_3$  with  $H_3$  = 0.1200 has its corresponding object points  $P_1$  with  $H_1$  = 0.1030 and  $P_2$  with  $H_2$  = 0.1961. In this case, the difference  $H_1 - H_2 = 0.0031$  is the minimum resolvable distance when the image height is around 0.1. The overall resolution data are illustrated further by two additional figures. Figure 16 is a pict of  $E_2$  -  $E_1$  versus  $E_3$  when  $C_3$  is located on the axis. It can be seen that, for the size value of  $[{\rm H_3}]$  and  $[{\rm H_3}] \sim$  0.01, the difference  ${\rm H_2}$  -  ${\rm H_1}$  is the h greater for positive  $\mathrm{H}_2$  than for negative  $\mathrm{H}_3$ . Thus, in order to minimize distortion and simultaneously pavimize the size of the image to be subtractor; one has to choose an optimum set of centers of images  $(C_1,\ C_2,\ C_3)$ 

For exactle, if the maximum tolerable difference ( $H_2$  -  $H_1$ ) is 0.001 and we place the upper end point of each of the input images 0.04 above its conten (1, 2, 2), the total height of the image can be subtracted would be 0.04 - (-0.15) - 0.19. If instead, when the middle point of the induce is placed at the 'center', the total height of the image that can be subtracted within the tolerance is then reduced to 0.04 - (-0.04) = 0.05. Figure 17 shows a different case in which the point  ${
m C_3}$  is not locate; at the optical axis but at  $C_2 = -0.050$ . Then it can be seen that the vilous of  $\langle \eta_{2} \rangle = \eta_{1}$  are almost distributed symmetrically around the center  $\langle \eta_{2} \rangle \approx$  $\Re M_{\rm P}$  . When the maximum thiorable  $\Re_9 \sim \Re_9^{-1}$  is 0.001 and the middle refets of the two error transparencies are placed at the centers  $\mathbf{C}_1$  and  $\mathbf{C}_2$  , the total set 0.5.75 %, in the state of to (0.3) = (-0.08) = 0.16. Note that in this case the distortion around the center change very slowly and have nealigible values. It is also interesting to find out the relative sisexclusing  $u_3 = 0$ . Two additional fig. tortion as defined by logures corresponding to the above-described two cases are plotted and shown in Figures 13 and 19 respectively. We can see that for the first case  $(\mathbb{C}_{\chi})$ locates on asis) the relative distortion is greater at the vicinity of the center than at the lower part of the image. For the second case ( $\mathcal{E}_3$  at  $\lambda_3$  = -0.05), the minimum relative distortion appears at the vicinity of the center. The total height for the first case within the telerance of  $\frac{H_2}{H_2} = \frac{H_1}{H_1}$ . It is about (-0.04) - (-0.16) = 0.12 while the total height for the second case is about 0.06 - 0.04 = 0.14. The computer programs for the calculations are listed in Appendix C and D respectively.

#### A. Conclusions

We have presented the principle, experimental data, and data draining of a real-time image subtraction technique by grip process properties of wave polarization. The theoretical analysis promptthat interference fringes should be produced in the system and the experiment? Buta demonstrated the enenomonor. The dark (or destructive interference) portion of the fringes can be used for cerforming thage unbiractions. The maximum area that can be used for subtraction in the , her we constructed is about 26 s.x 18 mm, which is almost order a half order of magnitude greater than that reported earlier of randings of a pitacles . In addition, in the present system, the deria tions are to a and the light efficiency is higher in coleanison with their rate . I lethaled calculation of the distrition of the image due to discretions also has revealed the optimum resitions where the input to per wheeld by placed at the input plane when the talerance of the difference of distintion error is set. From the experimental data. it seems that the Courier lens with the smallest D/F youlds the greatest abable of traction area. This is expected since in general lenses with greater final ber have less aberrations.

With remark to future work, it seems that two feasible ideas should be investigated. One is to incorporate the subtraction technique in an electro-optical system that includes the use of a Hughes liquid crystal light valve (CEV) for real-time image subtraction in a continuous mode. The other is to apply the Wolleston prism for performing real-time decadecelor image subtraction or additions. Both of these ideas could lead to incortant the treal application.

#### APPENDIX A

#### THE FUNCTION OF A WOLLASTON PRISM

Based on the nature of a Wollaston prism, light beam travelin: through the prism will gain an amount of rath-length according to trace Leam's orientation of polars, ation. To illustrate the effect, a x-z plane consequential of a Wollisten prism which consists of two triangle prisms is shown in Fig. Al. In h triangle has the apex A =  $\tan^{-1}$  (7/H), where wis the thickness and H is the height of the prism. The two triangle prisms are made of the same kind of birefringent crystal but have fifterent ortic axes. For our purpose, if the crystal is a "magarive" one, such in the calcite, the optic axis of the left half, as shown by " in Fig. Al. is parallel to waxis (or P<sub>1</sub>) and that of the right half (by 18%) is parallel to y-axis (or P<sub>2</sub>). Thus, for the light beam polarized after  $\mathbb{P}_2$ , the path length increment  $\mathbb{P}_1(x)$  is approximately.

$$\frac{1}{2} (x) = (\frac{1}{2} + x \tan A)(n_0 - 1) + (\frac{x}{2} - x \tan A)(n_0 - 1)$$

$$\frac{1}{2} (n_0 + n_0)(2 - 1) + x(n_0 - n_0) \tan A .$$
(A1)

Similarily, for the light beam polarized along  $P_1$  , the increment  $\mathbb{Z}_2(s)$  can be written as

$$(n_0 + n_e)/2 + 1] + x(n_0 - n_e) \tanh A$$
 (A2)

Based on the assumptions represented by equations (A1) and (A2), two important conclusions can be deduced. First, any plane wave after

traveling through a Wollaston prism will be deflected by an angle  $\epsilon$ , which is approximately equal to  $(n_0 - n_e)$  tanA. Because we have  $n_0 < n_e$  for a negative crystal,  $\alpha$  has a positive value, i.e., all plane waves coming from the points of  $S_1$  will be deflected downward by an angle  $\epsilon$  since they are polarized along  $P_1$ . The image of  $S_1$  at the output plane will then also be moved downward. It will be centered on the reaxis, if we make  $\epsilon \in \alpha$ . Since all light waves from  $S_2$  are polarized along  $E_3$ , the image of  $S_7$  will move usward and coincide with the image of  $S_3$ .

furthermore, the amplitude distribution at the Wollaston prism will not affect the calculated path length difference, yet, due to the focusing effect of  $\mathbb{L}_1$ , a Wollaston prism of relatively small operature can be used.

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#### ELUMRE CAPTIONS

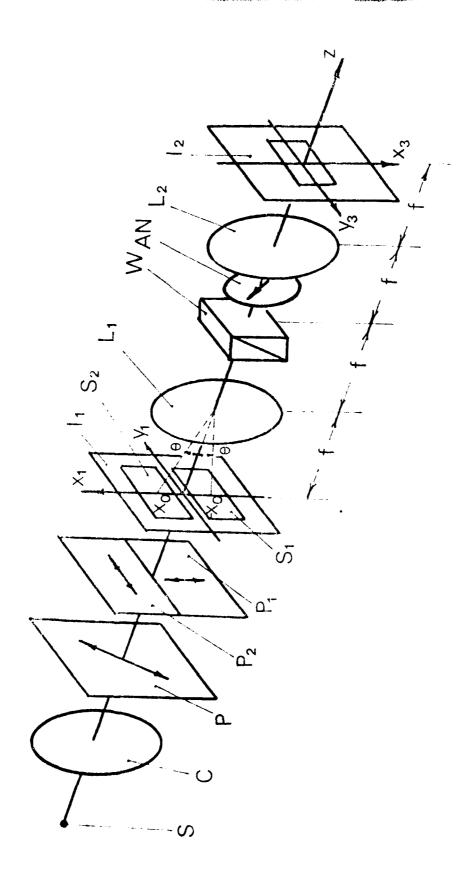
- A diagram of the polarization modulation white-light inductions subtaction system.
- F. Frincipal transmissance unit-vectors of the polarizers  $F, F_1, f_2, \dots$  the analyzer M.
- 5. Principal transmittance unit-vectors of P.  $\Gamma_1$ , Pg and A for the linear combination of two mages.

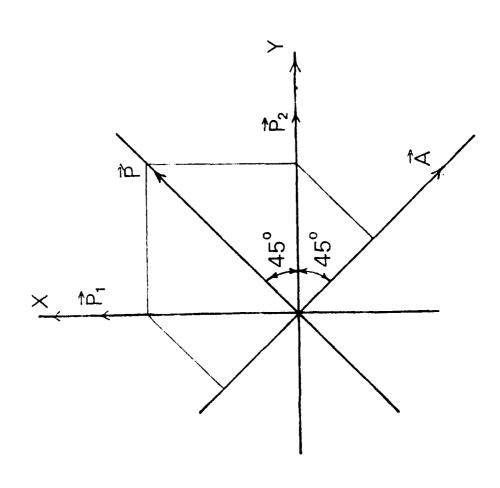
## 4. Photographs of interference fringes with $\mathsf{L}_1$ along Orientation 1 and the Wolfuston principal positions a and b.

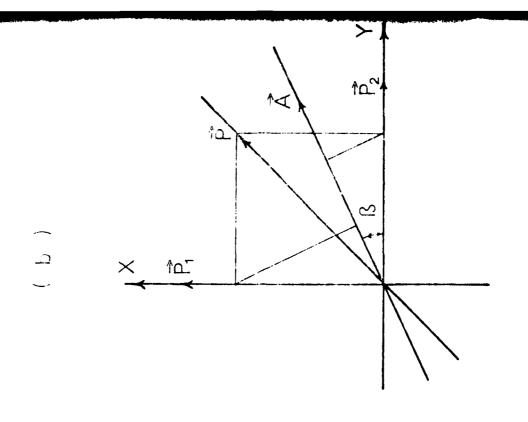
- ). Photograph of interference fringes with  $L_{\rm I}$  along Orientation 1 and the difference applies at positions a, b, c, and d.
- 6. Finite suppose in intercence (ringes with (a)  $t_{11}$  along Crientation ) and (i) along definition ().
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- 1). Photocomy, of cutput interference fringes with  $L_{11}$  placed alone orientation 1 and the Wollaston prism placed at four different testions a, b, c, and d alone the axis. No specific images were placed at the input place of the existem.
- 11. Photographs of the subtraction between a penny and a metal washer with the distance of separation between the two images varied.  $\mathsf{L}_{II}$  was placed in the system along Orientation 1 and the Wollaston prism was placed at position a as shown in Fig. 10.
- 12. Light rays originating from points  $p_1$  and  $p_2$  at the input plane reaching the point  $p_3$  at the output plane through the Wollaston prism.
- 13. The detailed parms of the light rays rassing through the Wollaston prices.

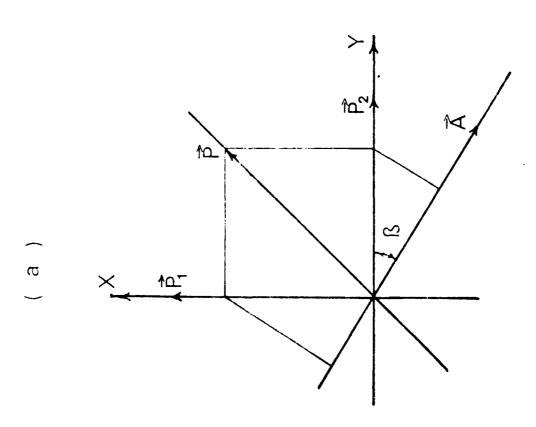
#### FIGURE CAPTIONS (Cent'd)

- 14. The methodally computed interference fringe nattorns versus the on-axial position of the Wollaston prism.
- 15. Relative positions of  $p_1$  and  $p_2$  at the input plane and  $p_3$  at the output plane for the computation of image distortion.
- 16 A plot of  ${\rm H_2}$   ${\rm H_1}$  versus  ${\rm H_3}$  with  ${\rm C_3}$  located on-axis.
- 17. Polot of  ${\rm H_2}$   ${\rm H_1}$ , versus  ${\rm H_3}$  with  ${\rm C_3}$  located off-axis.
- 18. A that of log (" ${
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- 19. A plot of log ([H<sub>2</sub> H<sub>1</sub>]/H<sub>3</sub>) with C<sub>3</sub> located off-axis.
- Al. A ker plane cross-sectional view of a Wollaston prism.

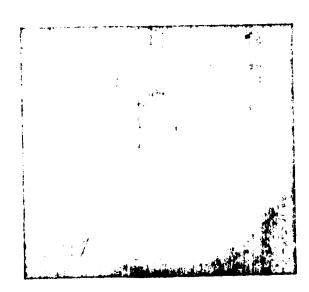






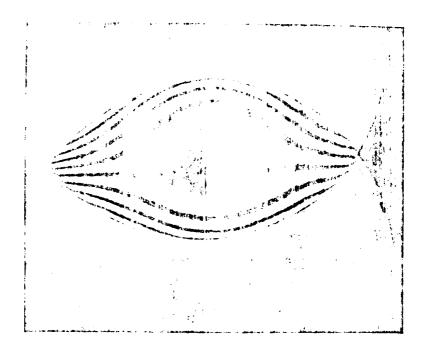


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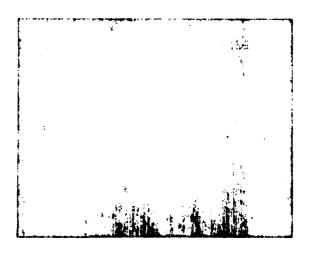


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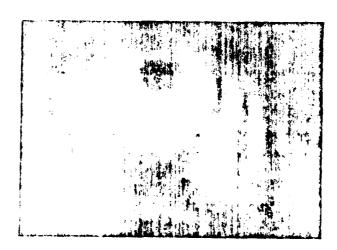
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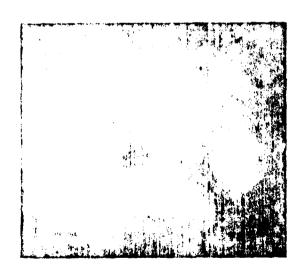


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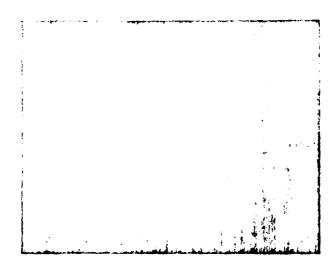


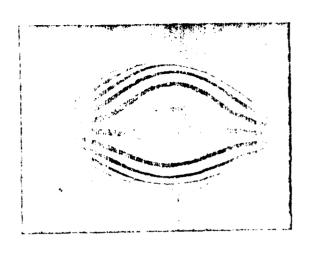


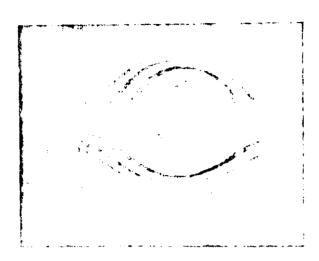




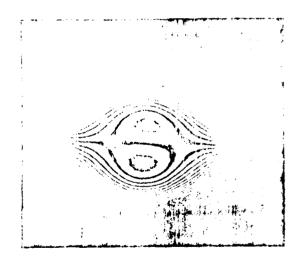
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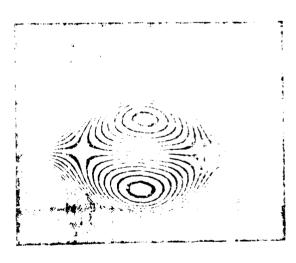






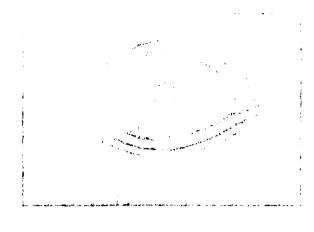


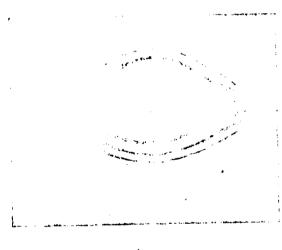




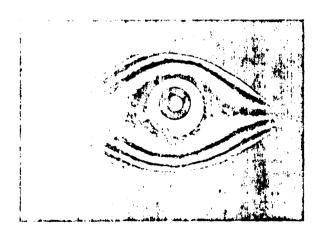
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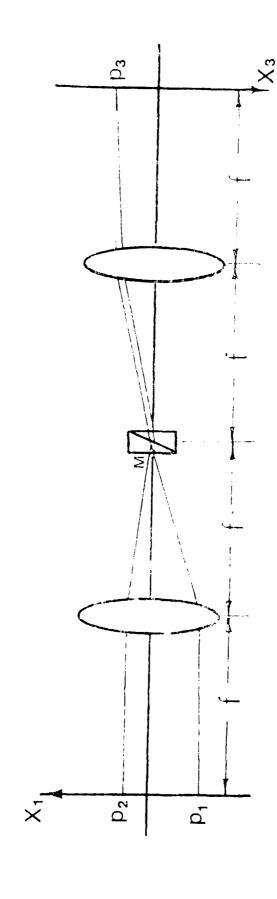
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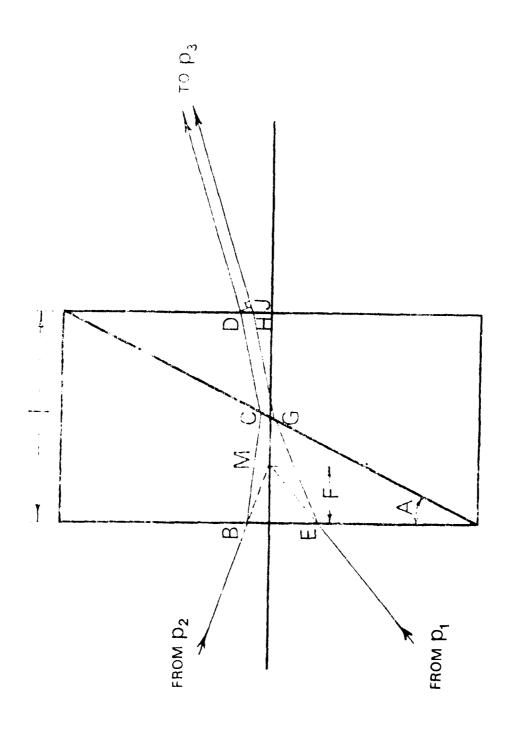


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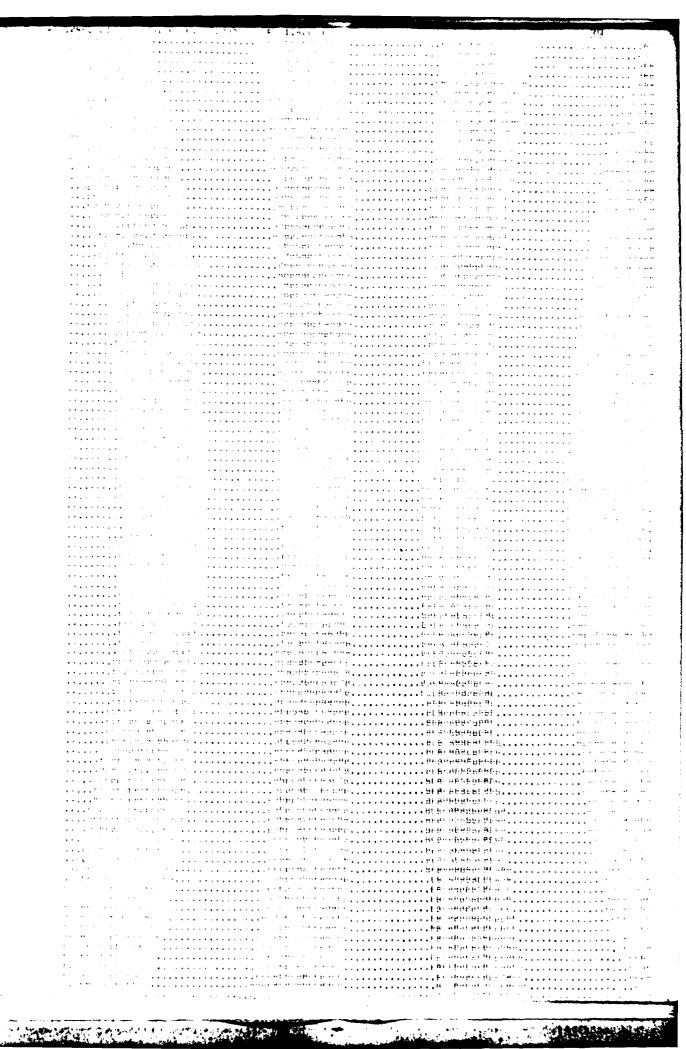




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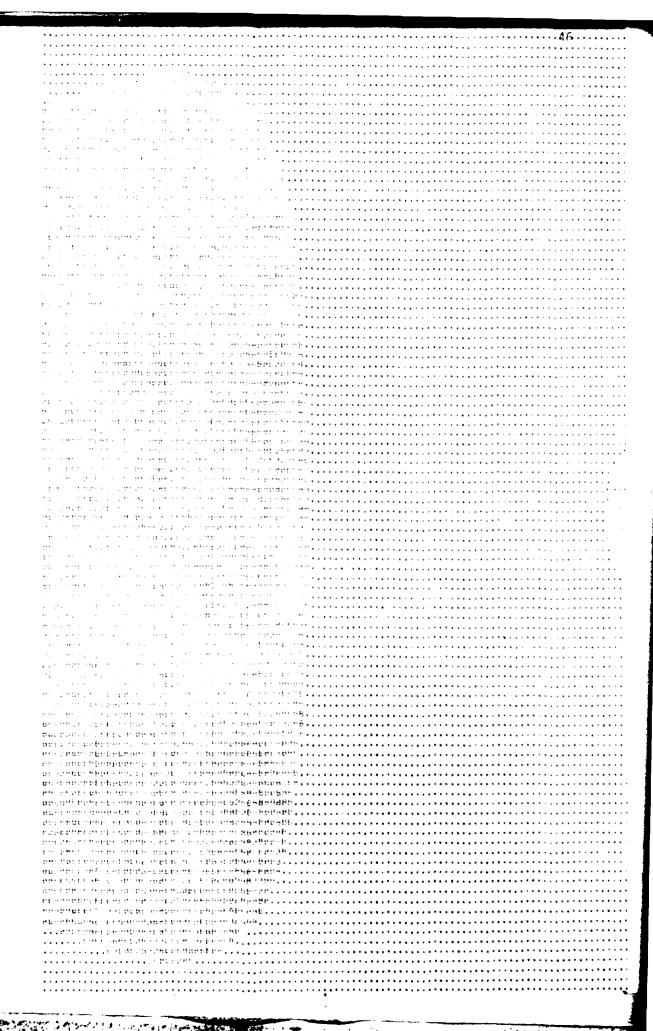
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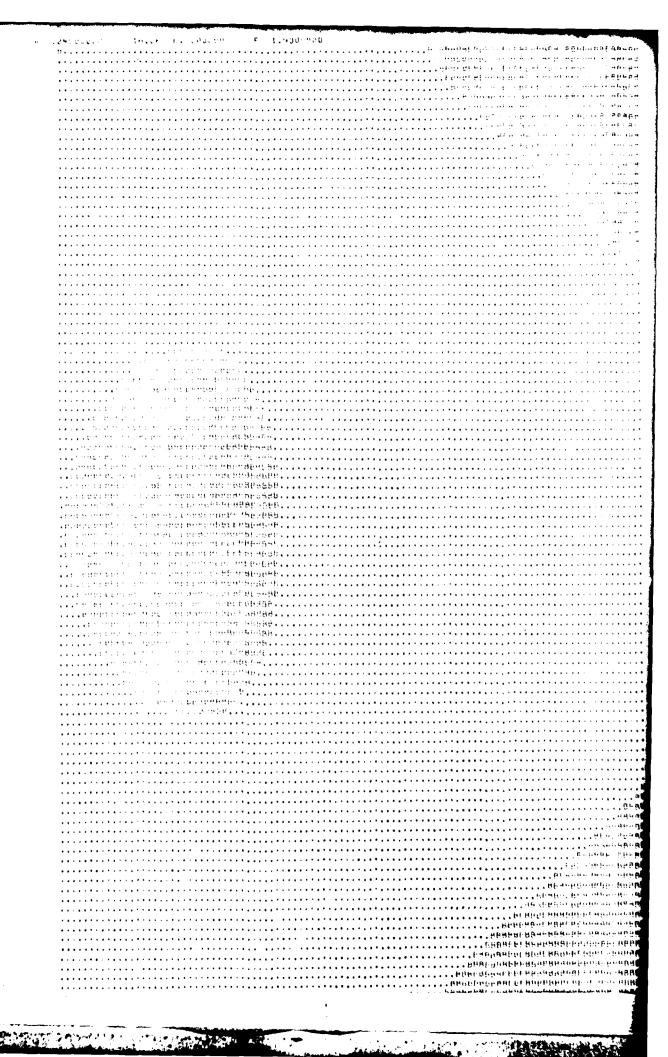
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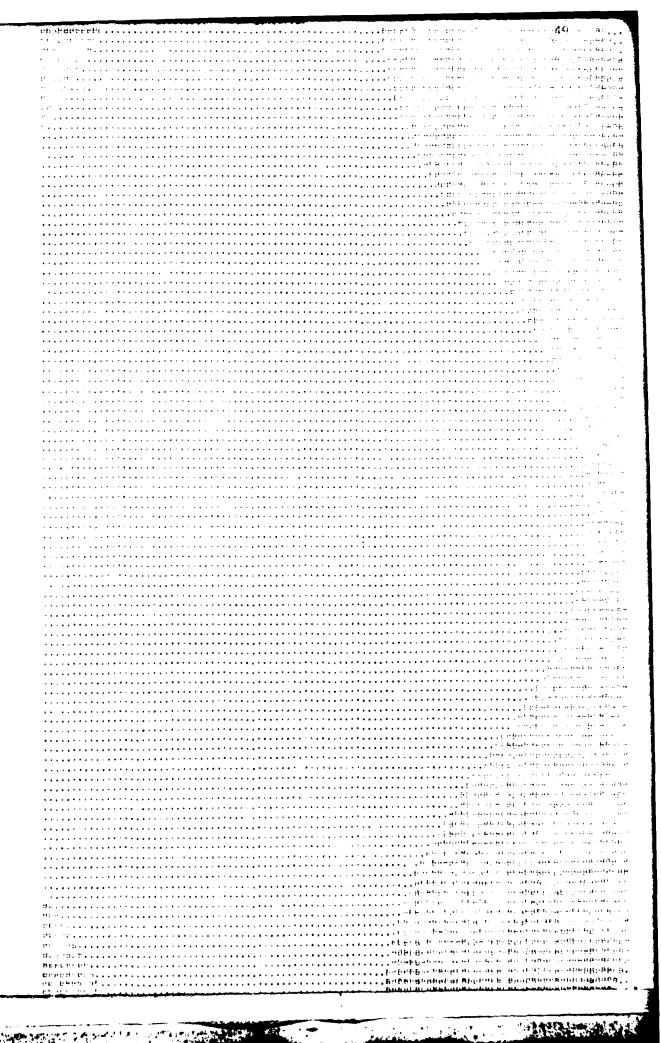
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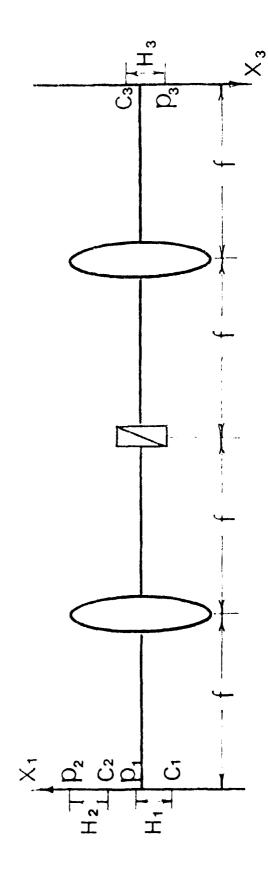
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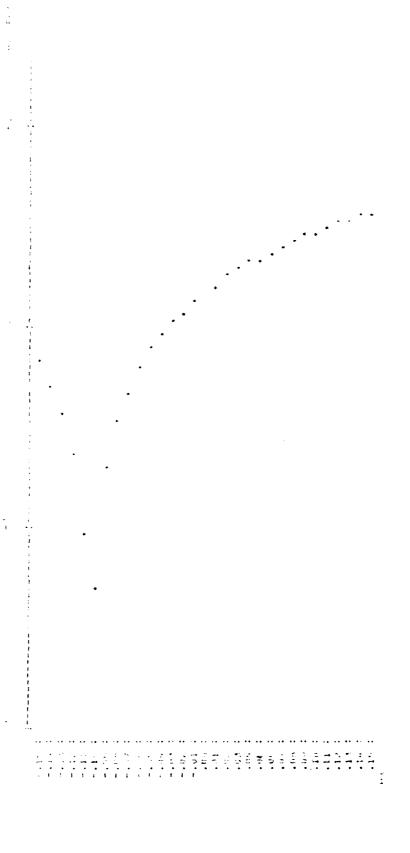
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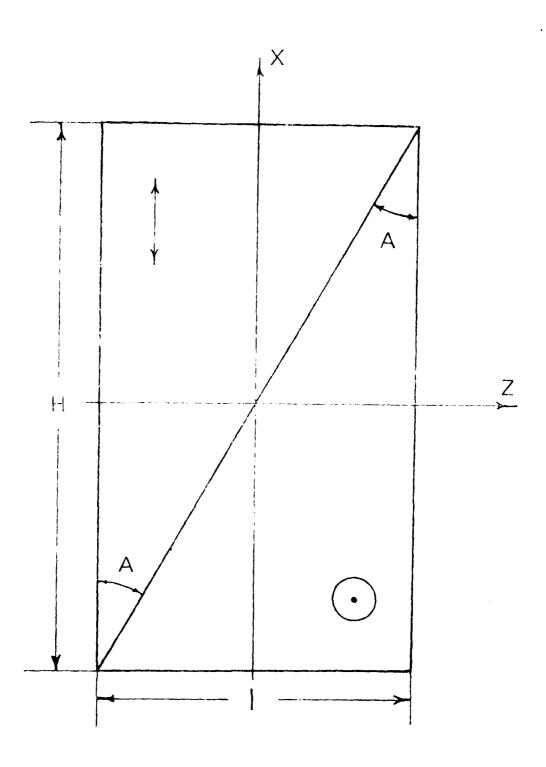
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